SIMULTANEOUS AUCTIONS IN TRANSPORT PLANNING OF MULTIPLE DERIVATIVES OF PETROLEUM IN MULTI-MODALS NETWORKS

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ABSTRACT

In supply chains of the petroleum industry, maintaining balancing between production and consuming of multiple products of petroleum derivatives is a crucial issue. Basically, this chain has several elements like producer bases, consumer bases, intermediary terminals that are linked by means of a multi-modal transport network. These elements should cooperate to reach the global balance of the system with the best transport cost. In this context, this paper proposes and compares two solutions based on auctions carry out with agents, which represent the elements of a supply chain. These solutions are characterized respectively for the execution of sequential auctions (i.e. one auction per time) and simultaneous auctions in order to consumers bid for batches of different kinds of petroleum derivatives. In the comparative tests carried out, the solution based on simultaneous auction is better than sequential one mainly because of the more intense cooperation among the agents.

KEYWORDS. multiagent auctions, petroleum derivatives, multi-modals network. Main area (Logistic & Transport and OP in the area of Petroleum & Gas).

1. Introduction

In the petroleum industry supply chain, the production and consumption tradeoff is a crucial issue. Whereas refineries should not stop producing because of lack of room for stocking oil derivatives, consumers should not be led to oil derivatives shortage once population and other industries depend on them. In this context, the concerned supply chain has several elements like refineries, intermediary terminals for storing oil derivatives, and means of transport linking refineries to terminals or consumers and terminals to consumers. All of them must work in a cooperative way to assure response to oil derivative demand at minimum cost. However, planning oil derivatives' transportations in this chain is a complex task. Indeed, it has been tackled by different kinds of approaches such as mathematical optimization and multiagent systems.

Among the mathematical optimization approaches, the Mixed Integer Linear Programming (MILP) technique has been largely used. For instance, (Magatão, 2004) uses MILP models for solving scheduling problems in pipelines, and (Neiro, 2004) tackles part of the supply-chain of a petroleum industry. These works illustrate the hard task of modeling wide systems with mathematical models. They consider parts of wide systems or they have to simplify their models in order to be computable. Nevertheless, when the models are well built, they are able to find optimal solutions.

In then, multiagent systems have been recently applied to supply-chain problems because there is a natural correspondence between model and reality (Wang, 2008; Zarandi, 2008). While in mathematical approaches, all the problem data must be condensed and centralized in a set of formulas, in a multiagent system data can be distributed among agents. Such agents represent refineries, means of transport, terminals and consumers that use the available information (or not) according to their goals and strategies. In some problems (e.g. task allocations and scheduling problems), multiagent approaches using auctions can find possible solutions in finite time generally faster than MILP models without significant degradation to the solution quality (Brito, 2009; Ertogral, 2000).

Auctions in multiagent systems are commonly associated to the competition for resources. Even if in a supply/consumption chain there is competition among consumers that cannot be in shortage of oil derivatives and producers that must flow their production, all of these agents try to reach a global goal: keep the balancing of the whole system. In this work, auctions are used as a mechanism of cooperation between agents in order to reach the global goal for multiples products delivery.

In this context, we have employed two approaches: one auction per time and simultaneous auctions in order to consumers bid for batches of many types of oil derivatives. Cooperation is implicitly achieved by setting priorities in auctions (who can be an auctioneer) and in participating in auctions. Both approaches are compared on the basis of a case study. The contribution is to propose a protocol for simultaneous auctions adapted to producer/consumer with zero balance problems that can be used by cooperating agents. Next section describes the particularities of the problem. Section III describes the theoretical fundamentals. Section IV describes sequential and simultaneous auctions approaches. Section V presents the results and section VI discusses the results. Finally, section VII gives a conclusion.

2. Conceptual View of the Problem

The problem of planning oil derivatives transportation in multi-modal networks is highly complex due to the quantity of elements, possibilities of routing, and constraints to these movements. It is practically impossible to draft a computable solution that addresses fully all the details of these networks (Felizari, 2009). Thus, abstraction is fundamental for achieving a solution. In the proposed approach, details of planning at operational level were omitted, only the planning at the tactical level is addressed.

The problem at the tactical level is the allocation of routes available to flow products from producers to consumers. The goal is to fully meet the market demand in a given planning horizon minimizing the cost of transport, respecting the capacities of the transportation modes, and the stocks at producers and consumers. Producers cannot produce more than their local stocks' capacities and consumers cannot run out of products. Routes are composed by one or more segments representing transportation means, which link producers to consumers. These segments are not necessarily of same type. For instance, a route composed of two segments can link a refinery to an intermediary terminal by means of a pipeline and link the intermediary terminal to consumer by means of a ship.

Fig. 1 depicts a chain of producers, consumers and storage terminals, which are called generally bases and are linked by several segments of routes (the arcs in the graph). The nodes in the graph (i.e. P1, P2, P3, T1, T2, C1, C2, and C3) represent the bases. Each base has a positive, a negative or a zero value specifying whether it is a producer, a consumer or a terminal storage (this last does not produce nor consume) for each types of product, which are two types of in the example. The node values are the initial balancing which is an input to the system coming from a higher level of planning. A particularity is that the sum of the balances to each product is zero. Thus, the movements must be performed accurately so that all bases finalize a planning period with their balances equal to zero.

In Fig. 1, segments of routes are identified by integer labels (ranging from 1 to 8). All segments are pipelines excepting segments 6 and 7 that represent links by ship. These segments are directed, which means that the flow follows only one direction. As planning is in the tactical level, there is no concern about the precise dates and order the products must be scheduled in the segments. One must only take into account the capacities of the segments per period of planning. Thus, the ship transportation capacity is directly obtained from input data, whereas the capacity of a pipeline segment is obtained by multiplying its flow in m^3/h by the number of hours in the period. Moreover, each segment has information about the transportation cost in $\$/m^3$.

However, in the planning execution, transportations must necessarily occur through registered routes. Between two bases, there may be zero or more than one registered route, and different routes may share same segments. Consequently, these segments' capacities are also shared. For a given route, the transportation capacity is limited by the lower capacity of their segments.

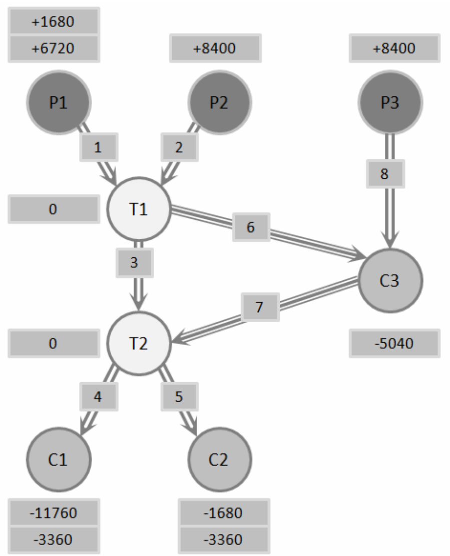

Figure 1. Transportation network.

3. Theoretical Fundamentals

Auction has been used as the cooperation mechanism among bases that negotiate the transportation of products in order to achieve a zero balance in each node. Two types of auctions, sequential and simultaneous, were experimented. The protocol of traditional simultaneous auctions was adapted to this problem trying to obtain better computational performance and better results in relation to measures of the problem domain. Elements of the modal network are modeled as agents of a multiagent system.

3.1 Multiagent Systems

According to (Jennings, 1999), an agent is a computing entity, situated in an environment capable to execute actions in a flexible and autonomous manner in order to reach objectives established in the moment of its conception.

An agent can be considered as a social entity when it interacts with other agents. In this case, these agents form a multiagent system (MAS). According to (Ferber, 1995), a MAS is characterized by the interaction among the agents in order to solve their own problems (e.g. optimize their internal process) by means of cooperation or competition.

Besides, (Sauer, 2003) makes a correlation between MAS and a supply chain system: “a supply chain can be seen as a society of autonomous agents, while a system of supply chain can be seen as MAS, where members of a supply chain are represented by different agents”.

3.2 Auctions

Sequential auctions are defined by the occurrence of only one auction at time, one after another, sequentially. These auctions are simple auctions that occur in accordance with the guidelines of the protocol of interaction called Contract-Net (Davis 1983). Basically, the Contract-Net protocol proposes two main roles in the process of interaction: the role of the auctioneer and the role of participants in the auction.

An auctioneer fires an auction by sending an announcement informing about the products, initial prices, and quantities to the participants. Such announcement is a call-for-proposals (CFP). Thus, each participant sends a PROPOSAL message containing its bid to the auctioneer. If the participant does not wish to participate in the auction, it sends a REFUSE message to the auctioneer. The auctioneer waits for a fixed deadline or the time required receiving all the bids of the participants. If deadline expires, the auctioneer only considers the bids received so far and starts processing to determine the winning bidder. The auctioneer sends an ACCEPT-PROPOSAL to the winner and REJECT-PROPOSAL messages to the other participants.

The winner participant receives the ACCEPT-PROPOSAL and returns an INFORM message to confirm the negotiation. In the case the winner desists of the negotiation, it sends a FAILURE message to the auctioneer. Finally, the auctioneer terminates the auction.

Auctions may have more than one cycle like this. In this case, the auctioneer sends another CFP to the bidders in order to initiate a new cycle. If the auctioneer does not receive any PROPOSAL message, the auctioneer believes the participants are already satisfied or unable to bid at the amount offered. Thus, the auction ends.

Another manner of carrying out auctions is by means of simultaneous auctions. Basically, this technique is defined by the simultaneous occurrence of several auctions at once. These auctions occur through an extension to the sequential auction mechanism and it is also based on the contract-net protocol (Krishna 2002).

4. Methodology

This section presents the two modeling approaches based on sequential and simultaneous auctions for the problem of transportation planning of several types of products in a multi-modal transport network.

4.1 Sequential Auction

In the sequential auction approach, the auctioneer role is performed by production bases and the bidder role by the consumer bases with which the auctioneer is connected. Producers and consumers bases are modeled by agents and the difference of a producer from a consumer is just the balance value signal. There are also agents which represent segments of routes and the Manager agent, which is responsible for controlling the system, doing tasks as startup/shutdown of all agents and ordering the auctions execution. Intermediary terminals were omitted for the sake of simplicity.

The multiagent system based on sequential auctions is executed in four phases: (i) initializing the agents, (ii) ordering the auctions, (iii) performing the auctions, and (iv) finalizing the agents. Besides, as there is a one-to-one correspondence between real world elements and agents, the word agent is omitted in next paragraphs. For instance, the expression “the producer agent” becomes “the producer”.

In the initializing phase, the Manager creates and initializes the agents with their respective input data. Then, the producers inform the Manager about their priority values to do auctions for each kind of available product. Priority values are calculated based on the number of consumers linked to a given producer for a respective type of product. The rationale is that producers with lower number of consumers have greater priority in doing auctions because they have few possibilities to flow oil derivatives to the consumers.

After that, Manager receives all the messages containing the priority values from producers, it sorts such values producing an ordered list whose head contains the producer with the highest priority. In fact, each list entry contains a pair (auctioneer, type of product). The Manager retrieves the first element in the list and notifies the auctioneer requesting it to start the auction. When the auction is finished, the Manager selects the next auctioneer and so forth.

Upon receiving the notification to be an auctioneer, the producer sends an announcement (CFP) to the consumers linked to it by some route that support the respective product. This CFP contains information about the product and the volume to be offered.

Receiving the CFP, each participant first checks how much of the offered volume is necessary to get closer to the zero balance. The necessary volume may be only part of the offered volume. Subsequently, the participant must determine the best route to receive the product if more than one route links the auctioneer to the consumer. For each route, the participant inquires all the segment agents in order to discover how much they can transport and the transportation cost, and then it selects the route with the lower cost. If there is a tie, the consumer selects the route which can transport the largest amount of the product (preferably the entire amount it needs).

The consumer forms a bid to the producer containing the required volume, the selected route, and the transportation cost per m^3. The participant sends a PROPOSAL message with the bid to the auctioneer. Participants may refuse to participate of any auction because of lack of capacity on the routes linking them to the producer or because they already achieved the zero balance. In both cases, they send a REFUSE message to the auctioneer.

The auctioneer waits for the time required to receive all the bids of the participants and starts processing to set the winner bid. The winner bid is defined first by the transportation cost and, in case of tie, by the largest ordered volume. Thus, the auctioneer sends an ACCEPT-PROPOSAL message to the winner and REJECT-PROPOSAL messages to the other participants.

If the auctioneer does not receive any PROPOSAL message, the auction ends and it notifies the Manager of its desire to no longer be an auctioneer (with respect to the given product) because of the impossibility of flowing the remaining volume. The same occurs when the auctioneer sells all the available volume.

When the winner receives the ACCEPT-PROPOSAL, it confirms the commitment of the segments of the selected route. Thus, capacities of the route’s segments are decreased to the next auctions. The winner updates its balance value and sends an INFORM message to the auctioneer confirming the deal.

The auctioneer receives the INFORM from the winner and updates its balance value with information about the dealing. At this point, if the auctioneer comes to the zero balance for the period, it sends a message to the Manager stating the desire to no longer be chosen as auctioneer. Otherwise, the auctioneer recalculates its priority and sends this information to the Manager.

Finally, the Manager receives the winner message, re-sorts the list entries and takes the head of the list to be the next auctioneer. This process repeats until the list be empty. At this point, the Manager starts the final phase sending completion messages to all agents for finalizing their executions.

4.2 Simultaneous Auctions

The simultaneous auctions approach uses the same three types of agents of the sequential auction: Manager, Base, and Segment agents. However, they have different behaviors that change the way they interact. The system based on simultaneous auctions is also composed of four phases: (i) initializing the agents, (ii) ordering the auctions, (iii) performing the auctions, and (iv) finalizing the agents.

The first phase is identical to the one of the sequential auction. In the second phase, the difference is in the way the Manager selects the producers for performing auctions of their various types of products. The third phase is also different because it consists of possibly more than one auctioneer performing auctions, where any auctioneer can perform more than one auction simultaneously, one for each kind of offered product. Besides, it is up to the Manager to determine the order in which auctioneers send the ACCEPT-PROPOSAL messages, and to assure that auctioneer sends ACCEPT-PROPOSAL messages one at a time to the winners.

The third phase begins when the producers receive notification messages from the Manager to start the auctions, with one auction for each product. An auctioneer sends an announcement (CFP) to the consumers linked to it by some route able to transport the product. This CFP contains information about the product and the volume to be offered.

Each participant receives at least one CFP. If the consumer is linked to more than one auctioneer, then the consumer participates of all auctions simultaneously. Thus, for each CFP received, the participant should prepare a bid.

Receiving the CFP, each participant first checks how much of the offered volume is necessary to meet its zero balance. The necessary volume may be only part of the offered volume. Then, the participant must determine the best route to receive the product if more than one route links the auctioneer to the consumer. For each route, the participant inquires all the segments in order to discover how much they can transport and the transportation costs. It selects the route with the lower cost and which can transport the largest amount of the product (preferably the entire amount it needs). When amounts offered by the producers in simultaneous auctions are not enough to fulfill the consumer needs, the consumer at least knows how much it can obtain from all auctioneers.

This information is important because it can express the urgency of a consumer to receive the products. Urgency is a measure used to avoid shortage of products in the consumer side. This measure tries to prioritize consumers with fewer opportunities to receive products. The smaller the amount of a product a participant can acquire with their auctioneers in a simultaneous auction round, the greater the degree of urgency for receiving this kind of product. This heuristic helps preventing shared segments to be occupied by other participants.

Each consumer sends a PROPOSAL message containing a different bid to each auctioneer. A bid provides information on the degree of urgency and also on the cost of the route chosen. Bids differs one from another by the selected route and the associated transportation cost.

Each auctioneer normalizes the urgency degrees and the transportation costs to a linear scale after receiving all the bids from the participants. The normalization of urgency degree (nUD) and transportation cost (nTC) is respectively calculated according to equation (1) and (2), by dividing the urgency degree (UD) or transportation cost of a particular bid (TC) respectively by the sum of UD values or TC values of all received bids in the round.

$$nUD = UD \Big/ \sum_{n=1}^{n} UD_n \quad (1)$$

$$nTC = TC \Big/ \sum_{n=1}^{n} TC_n \quad (2)$$

In order to determine the winner, the auctioneer scores the bids coming in PROPOSE messages from all participants according to equation (3), where the normalized values of urgency degree (nUD) and of transportation cost (nTC) are respectively weighted by wUD and wTC to give the bid score (BS). The participant who scores the highest bid is the winner.

$$BS = nUD * wUD + (1 - nTC) * wTC \qquad (3)$$

However, after determining the winner participant, auctioneers do not immediately send the ACCEPT-PROPOSAL to the winner. Firstly, the auctioneers request authorization to the Manager for sending the ACCEPT-PROPOSAL. The Manager gives one authorization at a time to the auctioneers taking into account the degree of urgency and, in case of tie, the transportation cost, both without normalization. Thus, prioritized auctioneers are those that have higher values for degree of urgency on their winner bids. If there is a tie, those with the lowest transportation costs are prioritized. This sequencing of ACCEPT-PROPOSAL messages is important to prioritize product transportations having greater degrees of urgency and to avoid inconsistence in the final allocation of capacity in shared segments of transport since two or more consumers could access capacity data of the same segment without concurrency safety properties.

Still, as allocations occur in the same round, the degree of urgency of the participants may change due to occupation of shared segments of transport. Thus, the bids of the participants waiting for an ACCEPT-PROPOSAL and consequently the priorities of the auctioneers waiting for sending ACCEPT-PROPOSAL messages should be updated in order the simultaneous mechanism may presents better results.

Therefore, each segment which receives a persistent allocation notifies all consumers linked to it by some route. Upon receiving of such notifications, these bases should update their degrees of urgency and notify their respective auctioneers with a message to update the bid. Thus, each auctioneer can compare the new value with the winner bid. If the update message is received from the current winner bidder, the auctioneer compares the new value with the old bid and if necessary, it updates its priority with the Manager to send the ACCEPT-PROPOSAL. Otherwise, if the update message is received from a participant other than the current winner bidder and the bid score is greater than the current bid, the auctioneer may change the winner bidder, and update its degree of urgency with the Manager to send the ACCEPT- PROPOSAL with the values received from the new bid. This practice is efficient, once the updating messages are only sent when the shared segments are allocated.

Therefore, there are two important points in this form of simultaneous auctions: (a) the bid to determine the winner in each auction and (b) the sequencing of the auctioneers for sending the ACCEPT-PROPOSAL to the consumers. The order of transmission of ACCEPT-PROPOSAL messages is highly important since the participants only want the amount of products they need. If an auctioneer has the transmission of the ACCEPT-PROPOSAL postponed, it may happen that the winner consumer no longer wants the product to which it gave the bid and then the winner consumer withdraws the auction. This situation occurs when the consumer has got the product with other producer. It is worthwhile to observe that when a consumer bids, it tries getting all the needed product volume to meets the zero balance from each producer it is linked to.

When a participant receives an ACCEPT-PROPOSAL, it checks if it still wants the volume to which it gave the bid. If it is the case, it sends an INFORM message to the auctioneer or otherwise, a REFUSE message. Before sending an INFORM message, it must firmly schedule the transport of the product with the segments composing the selected route. Also, it must update its balance for the planning period.

When the auctioneer receives the INFORM message, it updates its balance value, since the transportation was committed. However, if a producer still has the balance greater than zero for the period, it performs another auction. This auction does not occur simultaneously with any other. However, this auction follows the same process of simultaneous auctions, including intervention by the Manager to send the ACCEPT-PROPOSAL. This way the auctioneer has the opportunity to dispute the preference of consumers with other producers to cope with the volume remaining in the current round.

Finally, when an auctioneer receives only REFUSE messages, it considers that the participants are satisfied for the particular type of product and that there is no more opportunity to move it to them. When this occurs, the auctioneer informs the Manager to no longer be an auctioneer for that product. The auctioneer also informs the Manager to no longer be an auctioneer when its balance is zero for a given product in the period.

When the Manager's list of requests for sending ACCEPT-PROPOSAL messages becomes empty, it means that simultaneous auctions for all products are finished. Likewise, when there isn't any producer interested in being auctioneer of any product, the planning is finished and the finalizing phase is executed.

5. Results

This section presents a comparative study between the approaches based on sequential and simultaneous auctions using the scenario outlined in Fig. 1. This study aims at evaluating the quality of the solutions with respect to the cost of planned transportations and the fulfillment of the zero balance to two kinds of oil derivatives: gasoline and diesel. Producers and consumers balance values (m^3) to both products were initialized as shown in Table I. The sum of balance values of each product for producers meets exactly the demand of the consumers.

The bases are connected by segments of routes, for instance, pipelines or ships. Each segment is represented by an arc in the graph shown in Fig. 1. Table II presents data for each segment for the scenario in question. These data refer (a) to the cost of moving a cubic meter of oil, (b) the flow rate per hour for moving a certain volume of oil if the segment represents a pipeline and (c) the capacity of transportation in one period of one week.

TABLE I. BALANCE VALUES FOR THE BASES

	P1	P2	P3	C1	C2	C3	T1	T2
Gasoline	1680	8400	8400	-11760	-1680	-5040	0	0
Diesel	6720	0	0	-3360	-3360	0	0	0

Segments of Table II compose the routes presented in Table III. The route identifier provides information about the source base and the target base for a particular product, the segments that form the route and the concerned product types. In this context, the routes 1 and 2 are able to transport the two types of products.

The segments have limited capacity and many of them are shared by a number of routes. The existing routes also constraint the possibilities of transportation between bases. For instance, the base P1 flows products only to C1 and C2, P2 can only flows products to the base C1, and finally, P3 can flow products to C1, C2 e C3.

TABLE II. ROUTES' SEGMENTS

Segments	Modal	Cost ($/m³)		Flow (m³/h)		Capacity (m³)
		Gasoline	Diesel	Gasoline	Diesel	
1	Pipeline	$2	$2	60	60	10080
2	Pipeline	$2	--	50	--	8400
3	Pipeline	$2	$2	50	50	8400
4	Pipeline	$2	$2	90	90	15120
5	Pipeline	$2	$2	40	40	6720
6	Ship	$3	--	--	--	8400
7	Ship	$3	--	--	--	13440
8	Pipeline	$2	--	60	--	10080

TABLE III. ROUTES REGISTERED

Route ID	Product	Source Base	Target Base	Segments
1	Gasoline/Diesel	P1	C1	1,3 and 4
2	Gasoline/Diesel	P1	C2	1,3 and 5
3	Gasoline	P2	C1	2,3 and 4
4	Gasoline	P2	C1	2,6, 7 and 4
5	Gasoline	P3	C1	8, 7 and 4
6	Gasoline	P3	C2	8, 7 and 5
7	Gasoline	P3	C3	8

In turn, Table IV shows the final balance values for each base. The approach based on simultaneous auctions presented a satisfactory solution by allowing each base to meet a zero balance. In contrast, the approach based on sequential auctions has not provided the same quality for the solution, since not all bases achieved their goals. In a more detailed analysis, the producer P1 ended the period with a balance of 1680 m^3 for Gasoline and 6720 m^3 for Diesel. The consumer C2 was in need of 1680 m^3 of Gasoline and 3360 m^3 of Diesel. However, these movements could not be realized because there is not any route with capacity available between these bases.

TABLE IV. FINAL BALANCES

Auctions:			Sequential		Simultaneous	
Bases	Initial Balances		Final Balances		Final Balances	
	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
P1	1680	6720	1680	6720	0	0
P2	8400	0	0	0	0	0
P3	8400	0	0	0	0	0
C1	-11760	-3360	0	-3360	0	0
C2	-1680	-3360	-1680	-3360	0	0
C3	-5040	0	0	0	0	0
T1	0	0	0	0	0	0
T2	0	0	0	0	0	0

Table V shows the oil transportation comparing the sequential auction to the simultaneous auction approach. The table shows the volume transported by each route and the cost for transporting such volume for each type of product. This table shows that the sequential approach used only three routes, while the simultaneous approach used five routes to make their transportations. Considering approximately the occurrence of one moving per auction, one can conclude that the approach by simultaneous auctions performed more auctions than the sequential approach in this particular scenario. Even so, the runtime for both approaches was similar when measured on an Intel Core 2 Duo 2 GHz with 3GB of RAM. The average running time for both types of auctions was approximately 500 ms. Thus, the approach based on simultaneous auctions also presents a better solution when comparing the transportation costs with a processing time similar to the approach based on sequential auctions.

The bottom line of Table V shows the total costs for transportation obtained with each approach. These costs were calculated by the sum of the subtotal (i.e. cost of transportations actually done) plus the penalties (i.e. proportional to the non-transportation of products). The penalty is calculated by multiplying the absolute value of the volume of each non-balanced base by the sum of the more expensive route exiting from a producer base or arriving at a consumer base. The approach by sequential auctions was penalized with the amount of $21,840.00 because it did not move 1680 m³ of Gasoline and by $97,440.00 because of 6720 m³ of Diesel. For example, the penalty of $21,840.00 was obtained by the following calculation: 1,680 of P1 multiplied by 6 (corresponding to the cost of route 1) plus 1,680 of C2 multiplied by 7 (corresponding to the cost of route 6). Likewise, the penalty of $97,440.00 was obtained by the following calculation: 6,720 of P1 multiplied by 6 (corresponding to the cost of route 1) plus 3,360 of C1 multiplied by 10 (corresponding to the cost of route 4) plus 3,360 of C2 multiplied by 7 (corresponding to the cost of route 6). Thus, the total cost obtained by performing sequential auctions is $203,280.00 (sum of the $105,840.00 and $97,440.00) and the total cost obtained by performing simultaneous auctions is exactly $168,000.00 (sum of $127,680.00 and $40,320.00). Therefore, the total costs and final balances demonstrate that simultaneous auction is more advantageous than sequential one in this scenario.

TABLE V. VOLUME AND COST TRANSPORTATION BY ROUTE

Route	Sequential				Simultaneous			
	Gasoline		Diesel		Gasoline		Diesel	
	Volume	Cost	Volume	Cost	Volume	Cost	Volume	Cost
1	0	0	0	0	0	0	3.360	$20.160
2	0	0	0	0	1.680	$10.080	3.360	$20.160
3	8.400	$50.400	0	0	0	0	0	0
4	0	0	0	0	8.400	$84.000	0	0
5	3.360	$23.520	0	0	3.360	$23.520	0	0
6	0	0	0	0	0	0	0	0
7	5.040	$10.080	0	0	5.040	$10.080	0	0
SubTotal	16.800	$84.000	0	0	18.480	$127.680	6.720	$40.320
Penalties	----	$21.840	----	$97.440	----	0	----	0
Total	16.800	$105.840	0	$97.440	18.480	$127.680	6.720	$40.320

6. Discussion

This section discusses some limitations of the sequential auctions compared to the simultaneous auctions approach.

In general, the mechanism based on sequential auctions has not provided a satisfactory result because it consists of a simple solution to a problem that demands greater sophistication of control. More accurately, the sequential auction mechanism suffers from the simplicity of the policies used in two major decision points for solving the current problem: (a) the ordering of auctions and (b) the preparation of bids.

Regarding the first point, the policy used is not always consistent in the ordering of auctioneers. More precisely, the policy used to calculate priority of each auctioneer is based on the number of participants, being the greater the priority, the lower the number of participants. This policy doesn't work very well since it does not take into account the flow rate of routes to the participants and especially the required volume per participant.

Other policies could be proposed to achieve a better ordering for the auctioneers, such as those based on the number of routes or on their capacities. However, these policies may also fail, due to the number of routes or their capacities do not determine the actual degree of urgency for a producer to flow its production, since there may be routes with higher flow rates than others and only the flow do not represent at all the demand by customer base. So, for a coherent policy, it is necessary to know the volume demanded by each participant. However, this information is only known after the start of the auction, upon receiving of bids.

The same problem occurs with the simultaneous auctions approach. However, this problem is corrected by the occurrence of the second ordering performed by the Manager, which is used for the sending of ACCEPT-PROPOSAL messages.

Thus, the lack of a coherent policy for the ordering of the sequential auctions can result in undue transportations that prevent the agents to achieve a zero balance solution. For instance, the P2 was incorrectly put before the P1 to perform the auction, leading to the transportation of the entire volume required by C1 through the Route 3, which share the segment 3 with Route 1 and Route 2. If P1 does auctions before P2, certainly the shared segment would be occupied by products of P1. Thus, P2 would be forced to move its volume for C1 by Route 4, even this route has higher cost. The sequencing of the auctions in both approaches is presented in Table VI.

TABLE VI. AUCTIONS SCHEDULING

Routes	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Sequential	--	2º	1º	--	3º	--	--
Simultaneous	2º	1º/3º	--	6º	5º	--	4º

This ordering affects the quality of the solution of the sequential approach because each participant at the time of an auction does not know the possibility of getting the required product from another producer. In the example, C1 does not know the possibility of moving with producer P1 before or in the instant that receives a CFP from producer P2. However, this deficiency is corrected in the simultaneous approach, since each participant knows at any given time all the possibilities of transportation from the producer of each type of product. Thus, according to needs, a participant can indirectly ordering the reception of products to better allocate their available routes by means of the information encapsulated in its bid which is redirected to the Manager to scheduling the dispatching of ACCEPT-PROPOSAL messages. For example, C1 first receives the product diesel from P1 by route 2 and after gasoline from P3 and P2 respectively by routes 5 and 4. Thus, these choices allow it to achieve the zero balance.

Moreover, even if the problem of ordering auctioneers would be addressed in the sequential auction, an inconvenient would persist in the preparation of bids. In the sequential bidding only the value of the cost and volume of the best route are considered, which is not enough in a problem of such complexity.

To provide better results, the bid should include values for the degree of urgency that reflects more accurately the level of satisfaction of the consumer to receive the products of an auctioneer. The degree of urgency could be calculated according to the volume of a given product that a participant can obtain from all the producers linked to it by some route. However, this information is only available when the consumer received all CFPs for a given product. This is not feasible in practice due to the sequential mechanism. Thereupon, this deficiency generally diminished the quality of the final solution in sequential mechanism. Differently, the same problem do not occur so easily in the simultaneous auctions, since the policy used for the preparation of bids combines the values of the degree of urgency with the cost of best route.

Therefore, bids based only on cost are not a good policy to adopt, as a cheaper transportation can occupy completely a shared segment preventing it to transport products to consumers with higher degree of urgency. In the sequential auctions, this is due to the extremely local view of a participant in the generation of the bid. It only selects the best route and does not take into account the degree of urgency.

Thus, the simultaneous auctions approach seems to be more advantageous than the sequential one to the problem of transportation of oil derivatives. This is because the simultaneous approach is more sophisticated in generating bids. Besides, it demands cooperation of all agents for the sequencing of auctioneers. More precisely, it focuses on two important decision points of the auction: (a) auctioneers are ordered to send ACCEPT-PROPOSAL messages according to the bid score calculated on the basis of the value of the degree of urgency and the cost of the selected route selected and (b) participants generate bids to auctioneers also according to their degrees of urgency and cost of the selected route. The values calculated by the participants are of great importance for the good behavior of the system because it focuses on the consumers participating in the auctions in order to find the zero balance. The rationale of the system is that the consumers control the routes and also the sequencing of ACCEPT-PROPOSAL messages sent by the auctioneers so that they reach a zero balance.

7. Conclusion

This paper presented a comparison between two solutions based on multiagent sequential and simultaneous auctions applied to the problem of movement planning of multiple products of oil derivatives in a multi-modal transport network linking producers to consumers. In the case study, the approach based on simultaneous auctions presented a solution of higher quality than the sequential version. We can say that agents in simultaneous auctions cooperate implicitly with others by the degree of utility. Even though the global cost of transportation be important, achieving the zero balance is more important because it assures continue production at refineries (it is too expensive to stop refineries) and minimum stocks at consumers (the lack of certain oil derivatives can cause social disorder).

In short, this article shows that the approach based on multiagent simultaneous auctions can be potentially used as a tool for decision support for specialists in planning. For the sake of simplicity, the case study was very simple, but the simultaneous approach has also presented good results in more complex sceneries.

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